DOCUMENT RESUME

ED 243 786 SO 015 633

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TITLE Women and Mathematics: Research vs. Achievement in Education.
PUB DATE 83
NOTE 16p.; Paper presented at the Annual Midyear Conference of the American Educational Research Association Research on Women and Education Special Interest Group (9th, Tempe, AZ, November 3-5, 1983).
PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS Biological Influences; Educational Research; Elementary Secondary Education; Environmental Influences; Females; Males; *Mathematics Achievement; Mathematics Education; *Mathematics Skills; Nature Nurture Controversy; *Sex Differences; Sex Fairness; *Sex Stereotypes; *Spatial Ability; Teacher Attitudes; Teacher Influence

ABSTRACT

Many educators and researchers who believe that girls have less mathematical ability than boys associate this deficiency with girls' inferior spatial ability. This generally accepted belief that spatial skills are a major prerequisite for math achievement was tested through a study of the visual-spatial skills of a sample of 32 professional mathematicians. Subjects responded to the Witkin Embedded Figure Test and participated in brief individual interviews regarding childhood environment and recreational activities. There was little indication from the test that a strong or clear causal relationship exists between the subjects' ability to solve problems presented in the EFT and their achievement in mathematics. Moreover, interviews indicated no consensus that visual-spatial skills were useful to mathematics. Researchers suggest that environment rather than innate ability may be a key factor in math performance. Thus, the source and utility of visual-spatial skills might better be determined by observation and examination of education and experience in school and elsewhere rather than by a search for innate, fixed, and immutable cultural and biological factors. Teachers' beliefs that girls have less math ability than boys or that girls are unsuited for math-related careers can seriously affect the way they teach and what their students learn. (LP)

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WOMEN AND MATHEMATICS: RESEARCH ON APTITUDE VS. ACHIEVEMENT IN EDUCATION*

A SHORT TALK FOR THE 9th ANNUAL MIDYEAR RESEARCH
ON WOMEN AND EDUCATION CONFERENCE, NOVEMBER, 1983

Theodora Mead Abel, Robert Cogburn, and Phyllis Hersh

The most remarkable thing about research on women and mathematics is its contradictions. There has been a recent, nationwide increase of women graduates in engineering. At the University of New Mexico College of Engineering women students are succeeding in courses requiring considerable mathematical ability. However, in reading about research, the most popular theories seek to explain women's deficiency in mathematics and attribute it to genes, hormones, brain organization or the permanent effects of early childhood socialization. The media relate the latest scientific fad, be it sociobiology or brain lateralization, to female inferiority in mathematics. On the other hand, recent studies show no sex difference in verbal, spatial or mathematical measures (7), and Janet Hyde's analysis indicates that the difference between sexes on measures of verbal and spatial ability, where it is found, is very small (8). How can the incongruence be explained? And how does the research (and all the theory) relate to women's experience in education?

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*The research done at the University of New Mexico, which is described in this paper was done under the auspices of the Southwest Resourse Center for Science and Engineering.

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One relation is obvious: educational experience affects scores on cognitive tests, and women are now taking courses in areas that were formerly male-identified. In addition, performance on these tests is affected by motivation, self-concept and self-confidence (6, 16), and, for many women, these too have improved.

The effect of research on education is less obvious. The results of research, and the implicit or related theory, affect expectations in education, especially when research and theory attract the attention of the media and reflect common belief. Research that attracts the attention of the media gets wide publicity, but the findings are sometimes distorted, and often their significance is exaggerated. We are concerned with the effect this has on expectations for women in education in mathematics and mathematics-related areas.

Consider two examples. There are special mathematics classes in Albuquerque for fifth to eighth grade students who are exceptionally capable in mathematics. (The percentage of girls in these classes has increased from 30% to 44% in the past four years.) Girls do as well as boys in these classes, but teachers are less willing to recommend girls for the program because the teachers are afraid that the girls will be unable to compete. These are girls with unusually high mathematical ability. Their teachers' expectations may be based more on beliefs about their sex than on the fact of their achievement in mathematics.

In 1980 and 1981, twenty times as many women earned bachelor's degrees in engineering, in the United States, as in 1970-1971. As part

of a study to determine the factors that support or create barriers to the achievement of women engineering students, a questionnaire was distributed in a large, elementary computer science class . We were dismayed, but not surprised, to discover that 50% of the women respondents said that they had been actively discouraged from pursuing engineering careers by parents, peers, teachers or counselors. Less than 20% of the men students who responded said that anyone had tried to discourage them.

Those who believe that girls have less mathematical ability than boys usually associate this deficiency with inferior spatial ability, and this is generally accepted by researchers (and practitioners) in psychology and education (9,17) without careful consideration of the actual use of spatial skills in mathematics. We wondered if spatial skills were, in fact, a major prerequisite for achievement in mathematics, and decided to study the use of visual-spatial skills by a sample of professional mathematicians, subjects with proven (and demonstrated) mathematical ability and achievement.

We wanted to answer two questions: Do mathematicians have good visual-spatial skills? And how do they assess the importance of these skills for their work in mathematics? Our results suggest that the skill measured by the instrument we used (spatial or analytic ability) depends more on learning than on some fixed or innate ability, and does not have the causal relation to proficiency in mathematics that is usually assumed.

Our sample included 32 mathematicians. At the time they were tested, 19 had doctorates in mathematics and the others were advanced graduate students, of whom 10 had master's degrees. The sample included 8 women and 24 men (of European, Hispanic or Asian ethnicity).

We used the Witkin Embedded Figure Test (18) as a measure for several reasons. Performance on this test is recognized by researchers and those who review research as an indicator of visual-spatial ability (9, 13, 17). It is a research instrument, not commonly used in clinical or educational evaluation, and therefore a test with which our subjects would not have had prior experience.

Initially, 22 subjects were tested individually. Testing was followed by a brief interview consisting of a few questions about childhood environment (rural or urban) and past or current recreational activities (such as hobbies or sports). The complete test contains 24 items. Successful performance requires locating, as quickly as possible, a simple geometric form within a complex design in each item. The test is divided into two parts, A and B, and the score on each part is the mean time for 12 items.

After we analyzed the data, we noticed that scores for the second part of the test, part B, were much better than those for the first part. There seemed to be a large learning effect. However, improved performance on part B might also be attributed to a difference in the inherent difficulty of the two parts. For this reason, the test was administered to 10 additional subjects with part B done first. The

results, the mean scores for the two parts of the test for both samples and the significance of the learning effect are shown in the table. (The nonparametric Mann-Whitney test was used for tests of significance of the learning effect and the corresponding two-sample ranking method was used to obtain 95% confidence intervals.)

While the difference for part A is not significant, that for B is significant at the 5% level. In both cases there appeared to be a substantial learning effect, but the small samples (and one particularly difficult question in part A) make the results for part A less conclusive.

We found little indication that there is a strong or a clear causal relation between the subjects' ability to solve the problems presented in the EFT and their achievement in mathematics. In detailed interviews with 14 subjects we found no attribution of their achievement in mathematics to superior spatial ability and no consensus that visual-spatial skills are useful to mathematicians.

No subject in this sample said that high visual-spatial ability led him or her into mathematics or was responsible for his or her success. Several of the subjects said initially that they had little or no spatial ability, as indicated by tests in high school or their own or others' opinions. Is this surprising? Not really, because modern mathematics uses symbolic, algebraic statements much more than drawings or diagrams. Here verbal skills are needed. Edith Luchins and John Ernest, who are mathematicians, have questioned the overriding importance of spatial ability and noted that mathematics requires verbal ability and other skills as well (5, 11). Another mathematician, Anneli Lax, emphasizes the importance of using and understanding language in learning mathematics (10). This is not a new idea; Fennema

and Sherman (6) found correlations of verbal ability with performance in mathematics as did Aiken before them (1). Our view is that most problems in mathematics can be expressed in either verbal (algebraic or symbolic) or visual (geometric or diagrammatic) form. The particular method or approach to a problem that a mathematician chooses, whether algebraic or geometric, is the one most suited to the particular inclination of that mathematician, or the one with which he or she is most comfortable. This, too, can change with experience.

Our results do not support the theory that high achievement in mathematics is predicated upon visual-spatial skills. Consider this alternative: that studying mathematics promotes spatial ability. Visual-spatial skills may be acquired, along with formal course material, by those who take courses in mathematics.

In this study, we were in no sense taking a random sample from any population, nor did we intend to generalize our results to a larger group than our participants. However, the results were unexpected and, to us, extremely interesting, particularly because of the questions they raise about current educational theory.

Most subjects' performance improved radically after an experience lasting less than 15 minutes. A similar improvement was found in children's performance on EFT items (after a short training procedure) by Connor, Schackman, and Serbin (3). They suggest that differences which can be easily modified or changed by brief experience indicate the presence of environmental factors. On the other hand, more stable, fixed differences might indicate a genetic, heritable, or other innate factor. We did not find greater percentage improvement for subjects with better scores on the first set of items.

Considering the tremendous improvement in performance after such a brief learning experience, trying to solve twelve problems in a time period of approximately ten minutes, it does not seem plausible that the ability measured here is an inherent, permanent characteristic of the person tested. The subjects tested have considerable experience in mathematics and, in general, good scores on the EFT, but the magnitude of the learning effect suggests to us that this measure does not reflect their innate capacity for mathematics.

Would an innate ability that is predetermined or fixed by biological, social or cultural factors be so malleable and so easy to improve so quickly? We question the value of tests like the one we used to predict achievement in mathematics. We are concerned that students who do not have high scores on tests of spatial ability may be advised not to take advanced courses in mathematics, science and engineering. Similar advice might be given to students who are members of groups believed to have "inferior spatial ability." We would expect spatial skills to be improved by the courses such students might be counseled against taking.

We suspect that the source and the utility of visual-spatial skills might better be determined by careful observation and examination of education and experience in school and elsewhere rather than by a search for possible innate, fixed, and immutable cultural or biological factors.

In mathematics (as in science or engineering) a variety of skills and talents are used in creative work as well as in problem-solving (5). Why is spatial ability stressed and so much attention paid to a small sex-difference when the variation within each sex is greater and more obvious (8, 12)?

There are recent studies which show no such sex difference. For example, one found no differences in performance (by students in grades 9 through 12) on measures of verbal and spatial ability (7), and in another there was no sex difference on a test of geometric proof given to over one thousand (1364) students in all the geometry classes in 13 schools. (Geometric proof is something not likely to be learned outside of school. This seems to indicate that girls and boys can learn what they are taught equally well in mathematics.) (15)

Have you read about either of these studies in a newspaper or a popular magazine? Unfortunately, research results that offer an unfamiliar conclusion are usually known only to those in the field of research, while those that reflect and reinforce common belief are reported by the media (and readily accepted by the public).

Two years ago, at the University of New Mexico, a visiting scientist lectured about his work on hormone influence on the sexual behavior and the brain of the laboratory rat. He related its significance to the fact that men and women differ in that men have mathematical ability and women have verbal ability. In the next morning's newspaper, in an interview with him, the first paragraph said, "Girls have better verbal skills than boys, and boys have better math ability" (Albuquerque Journal, Nov. 20, 1981).

About three years ago, in Science (2), SAT scores of a sample of mathematically precocious 7th and 8th grade girls and boys were compared (2). (This test is usually taken in the 12th grade.) The authors attributed the difference in mean scores to "superior male mathematical ability, which may in turn be related to greater male ability in spatial tasks." The same data had been given a different interpretation earlier (4). The article in Science was covered by newspapers and magazines; one piece was entitled, "Do Males Have a Math Gene?" (Newsweek, Dec. 15, 1980). These are striking examples of research results extended to the entire human population, though based on samples that are hardly representative. We are concerned with the effect of this on education.

In our society, particularly in colleges and universities, students, including those who will become teachers, are taught to trust scientists, their research reports, and their opinions expressed in articles and books. Psychologist Abraham Luchins and his students examined 100 general psychology texts and found that 91% of them said that men have greater mathematical ability (11). This was the second most frequently cited sex difference; 100% said that men were stronger.

If teachers believe that girls have less mathematical ability than boys, this can affect the way they teach and what their students learn. A common belief in our culture is that women are unsuited for advanced education and careers in mathematics and science. Wide publicity is given to research results which appear to confirm this, and the attention of the media lends credibility to research which might otherwise be seriously questioned. Uncritical acceptance and frequent repetition of such results by professionals in education and

psychology contributes to a self-fulfilling prophecy by affecting teacher and student expectations and helping to create a discouraging educational climate for women.

Consider, for example, the idea of the importance of spatial ability. Why is it so difficult to give this up?

The late Carolyn Sherif described the way that performance on a test is transmuted into a property of the person tested. She said that, "the assumed validity rests upon some criterion measure, for example, the actual performance by a child in school. . . . In fact, such criterion tests of validity are seldom available in research on sex-differences" (16).

In this case, however, they are available in school records and in research like that on geometric proof described above. But, as Sherif predicted, these can be ignored, while evidence derived from laboratory research on rats (and birds and single-sex studies of people with endocrine abnormalities) is used to bolster belief in sex-linked human traits.

Have you ever heard of phlogiston? Before oxygen was discovered, fire was explained by the phlogiston theory. "Phlogiston" escaped when matter was burned. However, this, in turn, required phlogiston to have negative weight. Perhaps cognitive sex-differences have something in common with phlogiston, and sex-linked spatial ability is like negative weight, the latter needed to justify belief in the former.

TABLE

PART OF TEST	MEAN TIME (in seconds) Given First	Given Second	DIFFERENCE (before-after)	95% CONFIDENCE INTERVAL (before-after)	P value
A	28.22	20.05	8.17	-2.6 to 15.4	.1128
B	33.66	15.43	18.23	2.9 to 35.5	.0117

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